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**A CORROSION COMPARISON OF SEV-  
ERAL METALS USED AS CATHODES  
IN ELECTROANALYSIS**

BY

EDWIN HERBERT WEBSTER

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**THESIS**

FOR THE

**DEGREE OF BACHELOR OF SCIENCE**

IN

**CHEMICAL ENGINEERING**

---

**COLLEGE OF LIBERAL ARTS AND SCIENCES**

**UNIVERSITY OF ILLINOIS**

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Edwin Herbert Webster

ENTITLED A Corrosion Comparison of Several Metals

Used as Cathodes in Electroanalysis

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Chemical Engineering

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PART I

INTRODUCTION

There is little material available in the literature from from which a suitable comparison of the various metals ordinarily used for cathodes in electroanalysis may be drawn. The few studies that have been made are referred to in the bibliography and discussion; however, it was desired to learn something of the behavior of these metals when a series of quantitative electroanalyses were performed under identical conditions.

This was done by studying the successive losses by corrosion of a set of cathodes of the various metals used in precipitating the five metals commonly determined in the elementary state. From the data obtained it is to be noted that there is, in general, a superiority of one metal over another for the purpose.



## PART II

### HISTORICAL

From the empirical state of affairs common to every new branch of science the chemistry of electroanalysis has by reason of prolific investigation become fairly definite and well organized. However, there are phases in its application that are as yet undeveloped and insufficiently investigated.

Following the discovery by Nicholson and Carlisle in 1800 of the decomposition of water by the electric current, Cruikshank observed the separation of metallic copper, and suggested the galvanic current as a qualitative agent for the determination of the metals.

The discovery of galvanoplasty, known as electroplating, a technical process closely allied to electroanalysis, dates from 1839, as made by Jacobi.

Since then many investigators, prominent and unknown, have observed the electrolytic behavior of solutions of the salts of the various metals from the standpoint of the chemistry of the deposited metal. At first qualitative, then quantitative, the work has been extended to all classes of solutions, and to include many of the known metals, and also a few of the nonmetallic elements.

Attention of investigators has been largely drawn to the chemical reactions of the electrolytic cell, the metals suited to electrolytic deposition, the best solutions, and the proper



substances to be added to these solutions, whereas the source of the current, the physical conditions of the experiment, and the electrode materials have not been fully investigated, the last only casually by investigators in related fields.

For a period, now on the wane, it was believed that all elements could be determined electrolytically; this belief naturally stimulated research on nearly all the known metals, and nonmetals. In the course of this there were investigated and developed, the current sources, the vessels, the stirring devices, and simultaneous operation on many samples, however, there has been practically no work specifically on corrosion of electrodes by the electrolytes used in common electroanalytic practice.

The Division of Analytical Chemistry of the University of Illinois has been desirous of obtaining some criteria of the metals in common electrode use as to their resistance to corrosion in solutions of salts of the metals commonly determined electrolytically. There has been no previous work done along this line at the University of Illinois; this problem was taken up in 1920 at the suggestion of Dr. G.D. Beal with a view to obtaining information along this line.





## PART III

### EXPERIMENTAL

#### 1. Material

In the successful completion of an investigation such as this it is necessary to use metals whose salts may be obtained in forms which are easily and accurately determined, and of such a nature that comparable results may be obtained. To this end chemically pure silver nitrate, copper sulphate, copper nitrate, cobalt, sulphate, cobalt nitrate, nickel sulphate, nickel nitrate, and zinc acetate were used. The silver nitrate was 99.98% pure as tested by the average of three electrolytic determinations. Both the copper nitrate and sulphate contained iron, approximately 0.08%, which was removed from them by ammonia precipitation of each sample, giving a solution containing in addition to the copper salt, ammonium nitrate and sulphate, respectively. Similarly each solution of cobalt and nickel was freed from iron, for though iron does not interfere seriously with electrolysis of ammoniacal solutions, it is bothersome, and may cause results to include some mechanical error. All chemicals used were of either the J.T. Baker or Baker & Adamson make.

The concentration of all solutions used for the deposition was ascertained by strictly chemical as well as electrolytic methods, and the results compare very satisfactorily. The concentration of stock solutions was a variable, 0.003 to 0.005 g/cc of metal being the rule, save for the copper and zinc solutions; the concentration of the copper solutions was approximately 0.003 g/cc, and that of zinc 0.015 g/cc, expressed for the metals.



A description of the standardization of these solutions follows:

#### Silver Nitrate

25cc portions were analyzed gravimetrically by precipitation as silver chloride; the five determinations gave results of 0.1571, 0.1578, 0.1580, 0.1578, and 0.1577 grams of AgCl respectively. The average of these corresponds to a concentration of 0.11876 g/25 cc of 0.00475 g/cc of silver.

#### Copper Sulphate

25 cc portions were analyzed by the Low iodometric method as described by Treadwell-Hall<sup>1</sup> for sodium thiosulphate standardization; the sodium thiosulphate was standardized against C.P. copper. Four of these portions required, respectively, 12.78, 12.78, 12.78, and 12.80 cc of a solution of sodium thiosulphate having a copper equivalent of 0.006248 g/cc. This gives the value of the copper sulphate solution as 0.0031975 g/cc of copper.

#### Copper Nitrate

Similar determination of copper in this solution gave the concentration as 0.0041136 g/cc of copper.

#### Nickel Sulphate

Determination of the nickel as nickelodimethylglyoxime in 20cc samples gave weights of the glyoxime, amounting respectively, to 0.2910, 0.2912, 0.2909, 0.2913, and 0.2911 from the average of which the concentration of the solution was determined to be 0.002965 g/cc of nickel.

#### Nickel Nitrate

Similar analyses of this stock solution gave an



average value of concentration as 0.0029145 g/cc of nickel.

#### Cobalt Sulphate

The cobaltic hydroxide was precipitated by sodium hydroxide and bromine, was ignited, and reduced by hydrogen, in a Rose crucible, to metallic cobalt. By this method 25 cc samples of the stock solution gave 0.1475, 0.1475, 0.1476, 0.1474, and 0.1475 grams of metallic cobalt, corresponding to a solution concentration of 0.005900 g/cc of cobalt.

#### Cobalt Nitrate

Similar treatment of 25cc samples of this solution gave an average value of 0.1372 grams of cobalt, corresponding to a concentration of 0.005488 g/cc of cobalt.

#### Zinc Acetate

The zinc solution was analyzed by precipitation of zinc carbonate, and careful ignition of this to the oxide. Five determinations gave 0.1862, 0.1863, 0.1867, 0.1861, and 0.1864 grams of the oxide, respectively, corresponding to a concentration of 0.005989 g/cc of zinc.

By electrolytic analysis the following results were obtained:

#### Silver Nitrate

25 cc portions, electrolyzed according to a method given in Classen-Hall gave a concentration of silver of 0.004749 g/cc of silver, an average of four close checks.





### Copper Sulphate

25 cc portions, when electrolyzed, according to a method given in Classen-Hall<sup>2a</sup> gave 0.00320 g/cc as the concentration in terms of copper.

### Copper Nitrate

25 cc portions, to which were added 2cc of 6N  $H_2SO_4$  and 2 drops of 6N HCl, were filtered free from contaminating AgCl, and diluted to approximately 75 cc; to each was added 5 cc of concentrated  $HNO_3$  and one gram of urea. They were electrolyzed at 0.7-0.8 amperes and 3.0-3.5 volts for 80 minutes. The deposit of metal was dried by an alcohol wash, followed by the burning off of the alcohol. This is the method as used by the Division of Analytical Chemistry of the University of Illinois, and the concentration found was 0.00410 g/cc of copper.

### Nickel Sulphate.

This solution, analyzed according to the method given by Classen-Hall<sup>2</sup>, modified for the presence of nitrates, showed a concentration of 0.002911 g/cc of nickel.

### Cobalt Sulphate

The method for the determination of cobalt parallels that for nickel, and the same method was used as for nickel. The concentration found was 0.005904 g/cc of cobalt.

### Cobalt Nitrate

A concentration of 0.005478 g/cc of cobalt was obtained by a method identical with that described for the nickel nitrate.





# Zinc Acetate

The analysis was carried out according to Classen-Hall<sup>5</sup> in acetic acid solution. 1 cc = 0.00597 g/cc of zinc.

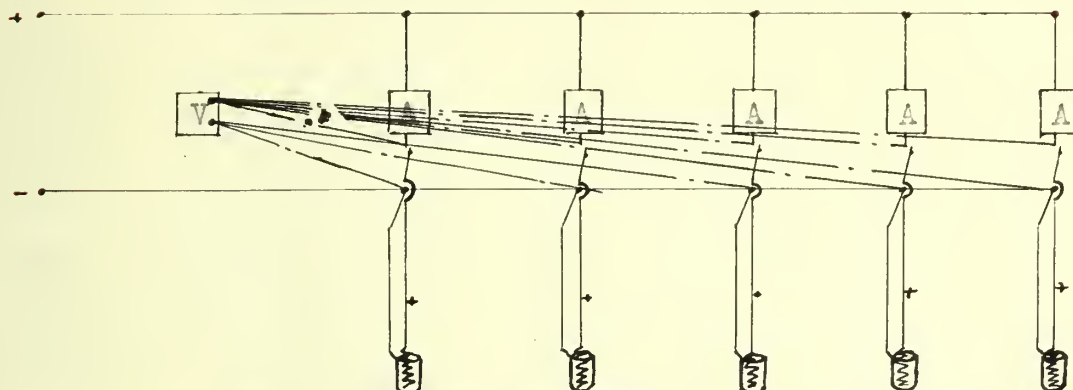
A comparative chart of the chemical and electrolytic standardizations of the salts employed, expressed in grams of the metal per cc of the solution follows:

	$\text{AgNO}_3$	$\text{CuSO}_4$	$\text{CuNO}_3$	$\text{NiSO}_4$	$\text{NiNO}_3$
Chemical	0.004750	0.003195	0.0041136	0.002965	0.0029145
Electrolytic	0.004749	0.00320	0.00410	0.002960	0.002911
	$\text{CoSO}_4$	$\text{CoNO}_3$	$\text{Zn}(\text{C}_2\text{H}_3\text{O}_2)_2$		
Chemical	0.0059	0.005488	0.005989		
Electrolytic	0.005904	0.005478	0.005970		

The values obtained by electrolytic analysis have been assumed as correct, because they are subject to exactly the same errors as occur later in the corrosion tests, compensating these. This work was all done on a special electrolysis setup, diagrammed on the following sheet, with stationary platinum cathodes of gauze, and rotating wire spiral anodes, in 200cc flat bottomed NonSol beakers.



DIAGRAM OF THE ELECTRICAL CONNECTIONS FOR THE TEST  
ELECTROLYSES. CATHODES STATIONARY, ANODES ROTATING.



THE DIAGRAM OF THE SETUP FOR THE STATIONARY ELECTROLYSES IS EXACTLY SIMILAR.

LEGEND:            A --- Ammeter  
                  V --- Voltmeter

REMARKS:            An ammeter for each circuit, and one  
voltmeter connected with all or any of the five circuits, was  
the scheme used for as nearly uniform conditions of electro-  
lysis as possible.



PART III  
EXPERIMENTAL

2. Procedure

The tests were made by the parallel analysis of five equal portions of the same stock solution, at identical voltages and current strengths, for the same lengths of time. Five "runs" were made on each reagent, and assuming the complete deposition, after the proper tests were made, the loss in weight of the electrode was calculated from its last previous weight, alone. The electrodes save the silver one, were cleaned by nitric acid of a density pf 1.20 g/cc. The silver one was cleaned by means of concentrated hydrochloric acid and hydrogen peroxide. All drying of electrodes was done at the temperature range of 100°-105°C for one half hour, this having been found in all cases, to be sufficient for the present investigation, with no accompanying danger of oxidation of the metals. The time of the electrolysis was without exception one hour for the stationary work. In the case of the cobalt and nickel electrolyses there was added to the mixture C.P. ammonium sulphate, to increase the conductivity of the solution.

The electrodes used for investigation were of gold gauze, platinum sheet, platinum gauze, "Palau" sheet, and silver gauze, for the revolving anode work. For the stationary work a gold dish, a silver dish, and two of platinum were used, each with a platinum sheet anode, suspended by platinum wire into the electrolyte. These are the common metal electrodes as used in the laboratory of the Division of Analytical Chemistry of the University of Illinois.





PART IV

RESULTS

(a) With cylindrical stationary cathode and rotary wire  
screw anode the following data were obtained:

1. Silver in Silver Nitrate

Cathode (Metal)	Weight Before Electrolysis					Average Loss During All.
	1	2	3	4	5	
Gold	7.6559	7.6559	7.6559	7.6560	7.6559	-----
Silver	10.4245	10.5432	10.6620	10.7808	10.8993	* 0.1187 g.--
Palau	10.6234	10.6233	10.6232	10.6231	10.6230	--0.0001 g.--
Pt(gauze)	16.7835	16.7835	16.7835	16.7835	16.7835	-----
Pt(sheet)	9.4013	9.4014	9.4013	9.4012	9.4013	-----

2. Cobalt in Cobalt Sulphate

Cathode (Metal)	Weight before Electrolysis					Average Loss During All.
	1	2	3	4	5	
Gold	7.6559	7.6558	7.6559	7.6561	7.6160	-----
Silver	10.7664	10.7035	10.4045	10.2727	10.1321	--0.1561 g.--
Palau	10.6234	10.6231	10.6233	10.6230	10.6229	--0.0002 g.--
Pt(gauze)	16.7836	16.7833	16.7836	16.7835	16.7836	-----
Pt(sheet)	9.4014	9.4013	9.4014	9.4013	9.4013	-----

3. Cobalt in Cobalt Nitrate

Cathode (Metal)	Weight before Electrolysis					Average Loss During All
	1	2	3	4	5	
Gold	7.6559	7.6559	7.6559	7.6555	7.6557	--0.0002 g.--
Silver	10.2263	10.2747	9.3217	8.7941	8.6480	--0.4067 g.--
Palau	10.6234	10.6231	10.6233	10.6230	10.6229	--0.0003 g.--
Pt(gauze)	16.7835	16.7835	16.7835	16.7835	16.7836	-----
Pt(sheet)	9.4013	9.4013	9.4013	9.4012	9.4014	-----

4. Nickel in Nickel Sulphate

Cathode (Metal)	Weight before Electrolysis					Average Loss During All
	1	2	3	4	5	
Gold	7.6558	7.6559	7.6559	7.6555	7.6557	--0.0001 g.--
Silver	10.8993	10.8816	10.8641	10.8460	10.8284	--0.0227 g.--
Palau	10.6232	10.6233	10.6234	10.6232	10.6229	--0.0001 g.--
Pt(gauze)	16.7835	16.7833	16.7835	16.7833	16.7834	--0.0001 g.--
Pt(sheet)	9.4012	9.4013	9.4014	9.4014	9.4012	-----





PART IV

RESULTS

(a) With cylindrical stationary cathodes and rotary wire screw anodes the following data were obtained.

5. Nickel in Nickel Nitrate

Cathode (Metal)	Weight before Electrolysis					Average Loss During All
	1	2	3	4	5	
Gold	7.6559	7.6558	7.6558	7.6557	7.6559	-----
Silver	10.8101	10.8051	10.7999	10.7940	10.7888	--0.0078 g.--
Palau	10.6234	10.6235	10.6233	10.6235	10.6234	--0.0001 g.--
Pt(gauze)	10.7835	10.7834	10.7833	10.7835	10.7835	-----
Pt(sheet)	9.4013	9.4013	9.4013	9.4013	9.4014	-----

6. Copper in Copper Sulphate

Cathode (Metal)	Weight before Electrolysis					Average Loss During All
	1	2	3	4	5	
Gold	7.7853	7.7850	7.7851	7.6561	7.6559	* special----
Silver	10.8307	10.8420	10.8209	10.7786	10.7674	--0.0186 g.--
Palau	10.6240	10.6234	10.6238	10.6233	10.6234	--0.0004 g.--
Pt(gauze)	16.7835	16.7835	16.7835	16.7833	16.7838	--0.0001 g.--
Pt(sheet)	9.4010	9.4011	9.4011	9.4011	9.4013	--0.0001 g.--

7. Copper in Copper Nitrate

Cathode (Metal)	Weight before Electrolysis					Average Loss During All
	1	2	3	4	5	
Gold	7.6559	7.6558	7.6559	7.6558	7.6559	-----
Silver	10.7566	10.7454	10.7342	10.7220	10.7101	--0.0118 g.--
Palau	10.6233	10.6232	10.6234	10.6234	10.6233	-----
Pt(gauze)	16.7835	16.7835	16.7835	16.7835	16.7835	-----
Pt(sheet)	9.4013	9.4014	9.4013	9.4012	9.4014	--0.0001 g.--

8. Zinc in Zinc Acetate

Cathode (Metal)	Weight before Electrolysis					Average Loss During All
	1	2	3	4	5	
*Gold	9.9770	9.9770	9.9770	9.9770	9.9770	-----
Silver	10.6998	10.6994	10.6956	10.6940	10.6920	--0.0019 g.--
Palau	10.6233	10.6234	10.6233	10.6234	10.6234	-----
*Pt(gauze)	16.9751	16.9750	16.9748	16.9747	16.9745	--0.0001 g.--
*Pt(sheet)	9.5927	9.5927	9.5927	9.5927	9.5927	-----

\* Plated with copper to prevent the formation of platinum black and black gold which are easily lost mechanically. A gold



complex is formed which is soluble, if the electrode is not protected by copper.

The item marked "Average Loss During All" is the average of the four losses as indicated between the five successive weighings in each case. The item marked \*special, for Gold, under 6. Copper in Copper Sulphate, is a corrosion loss of gold due only to the use of nitric acid of specific gravity 1.42, concentrated to that point by allowing it to stand upon a steam bath over night, with the electrodes in it.

The loss of weight of the electrode is that occurring both during the electrolysis and the succeeding cleansing; the method for cleansing has been previously mentioned.

In the case of the zinc electrolysis it was advisable, inasmuch as the purpose of the study was the chemical and electrolytic action of the reagents, to prevent the purely mechanical losses due to the formation of platinum black and black gold, as well as the soluble gold complex solution loss. However a few determinations were run on some gold and platinum wire as cathodes, and the results are of interest; they follow:

#### 8. Zinc in Zinc Acetate

Cathode (Metal)	Weight before Electrolysis			Average Loss During All
	1	2	3	
Gold(wire)	0.0341	0.0237	0.0114	0.0113 g.---
Plat.(wire)	0.2746	0.2723	0.2710	0.0018 g.---



PART V

DISCUSSION

There are several points to be taken into consideration in a survey of the results of this work, including all the physical conditions, as temperature, voltage, amperage, current density, time, and the character of the deposit. The latter two points are very closely related and if all apparatus be strictly clean and free from any grease, such as body oils from the fingers, it is found that the longer the time of deposition the greater was the density of the deposit, and its adhesion and cohesion. Of course such a comparison is true as applied to only one metal at a time.

For the purposes of discussion it seems well to mention first the simple electrolytes, and later the more complex. Of the simple type the ones used were silver nitrate, copper sulphate, copper nitrate, and zinc acetate. The complex electrolytes were the solutions of cobalt and nickel salts. The word complex is used in this sense to express the fact that the metallic radical to be deposited exists in the solution in a form in which its primary ionization is as a complex ion which then ionizes to a lesser extent into the cation to be deposited.

The reactions taking place in the electrolysis of silver nitrate, for example, are primarily  $\text{Cu}(\text{NO}_3)_2 \rightarrow \text{Cu} + 2\text{NO}_2$ . The copper ion, migrating to the cathode, takes up one electron and is deposited as the element; the  $\text{NO}_3$  radical while migrating toward the anode reacts with the water to produce free nitric acid, with a liberation of molecular hydrogen at the anode. There is





also liberation of hydrogen from the cathode, though this is not as marked as the evolution of oxygen. It is well known that this procedure requires the presence of a considerable excess of nitric acid or the solution will become alkaline with an actual odor of ammonia at the end of the electrolysis, in which case the solution assumes a deep blue color, and the metal deposited is contaminated with oxide. This condition is brought about by the action of the electric current on the  $\text{HNO}_3$  to produce nascent hydrogen which reduces the nitric acid to ammonium nitrate, perhaps according to an equation resembling  $4\text{H}_2 + \text{HNO}_3 \rightarrow \text{NH}_3 + 3\text{H}_2\text{O}$ . The sulphate, on the other hand, does not suffer such reduction, and ammonium sulphate will not be present save as traces. In the electrolysis of zinc acetate it is necessary to have a large excess of acetate ion to prevent the solution from becoming contaminated by the products of the discharge of the acetate ion.

In the electrolyses of the cobalt and nickel complexes the metals are present in the complex cations, as in  $(\text{Ni}(\text{NH}_3)_4)$ , which undergoes a secondary ionization and equilibrium, as  $\text{Ni} - 4\text{NH}_3 \rightleftharpoons \text{Ni}(\text{NH}_3)_4$ ; cobalt behaves in this respect similarly to nickel. To prevent the formation of the characteristic nickelous and cobaltic hydroxides it is necessary to have present a high concentration of  $\text{OH}$  ions, accomplished by excess ammonium hydroxide. This also lowers the concentration of the Co and Ni ions but prevents the formation of the oxides and oxide hydrates.

It seems from the result obtained that the silver is susceptible to loss both in the acid and the alkaline solutions, and there is little preference for either, though the losses in the





zinc electrolysis is markedly lower than in acid electrolytes. This is a point in favor of the electrodes of this metal, even by the beginning student in electroanalysis. The average error in their use would seem to be in the neighborhood of 0.0200 grams in each electrolysis, and though the acetic acid solution shows the lowest, with an average loss of only a little over 0.0019 grams, and the nitric acid next lowest with an average loss of a little over 0.0100 grams per run, the latter would correspond to 1% of a gram sample, and correspondingly more if the rating be on the percentage of the element determined. The gold cathode lost slightly on first being used in copper sulphate, but after several cleanings and succeeding use, assumed a constant weight, having apparently become passive, by the action of the nitric acid employed in the cleaning. The "Palau" electrode was somewhat better than the gold in the matter of corrosion, but for some reason the deposit on a cathode of this metal was of a less dense character, and times it was quite difficult to get a good adherent and coherent deposit. Also this electrode tarnished easily and all the colors of the rainbow would be apparent at the end of an alkaline electrolysis on that portion of the metal which had not been immersed in the electrolyte. This is the reverse of what would be expected for customarily the lesser current densities produce the denser deposits, and the "Palau" electrode, on account of its larger size, and consequent greater surface, had a lower current density in its use than the others.

As would be expected, the platinum electrodes, both sheet and gauze, remained almost constant in weight. The only corrosion



losses of the platinum, of consequence, occurred in the determination of zinc, which apparently forms a surface alloy, diffusing somewhat into the platinum, and yielding a spongy deposit of platinum black on cleaning the electrode with hydrochloric acid or sulphuric. Such a friable deposit is easily lost, and at best hard to wash clean and dry well. For this reason the zinc electrolyses were first run on small, relatively useless, bits of wire of platinum and gold, as gold is similarly affected. Then the electrodes were copper plated and in such a condition it was found satisfactory to use them, though there was a steady and consistent loss of approximately 0.1 mg at each usage. This use of copper makes the zinc electrolyses a study of the corrosion of copper on those electrodes which were so plated, the gold and platinum, the silver and palau, used without this protection are studies of the effect on these metals direct.

In the original plan of this investigation we had the idea of investigating tungsten, molybdenum, tantalum, and "Illium" electrodes as well, but this had to be abandoned, due to the difficulty of obtaining material suited to the work.

Stationary electrodes were found to be very unsatisfactory inasmuch as a much greater dilution was required, and over eight hours time in continuous electrolysis was necessary to get a complete deposition of the metal. Within that length of time the source of current would vary somewhat, at times was negligible in quantity, and there was a serious loss of water by evaporation of the electrolytes during that length of time, with consequent concentration of the solutions.



In one case when the analysis was left, at the end of four hours it was in excellent progression, but at the end of the next four practically all the deposited copper had been redissolved by the then concentrated nitric acid or remained light and dry on the sides of the dish, mixed with the salts produced by evaporation. It was found necessary for present purposes to provide for the replenishment of the water of the solution.

Two analyses each were obtained for copper in copper sulphate only, on the three metals, gold, silver, and platinum, out of some forty trials. Their results are tabulated below. Other electrolyses, of cobalt, nickel, and zinc, were tried out but proved unsuccessful.

#### 5. Copper in Copper Sulphate

Cathode (Metal)	Weight before Electrolysis		Average Loss During All
	1	2	
Platinum	37.9041	37.9040	-----
Platinum	43.7818	43.7818	-----
Silver	31.3742	31.1718	--0.2024 g.--
Gold	48.6309	48.6310	-----





PART VI

SUMMARY

In summing up the results of this investigation it must be admitted that there is no logical way of expressing the corrosion losses found, in terms of any absolute values which might lead to theoretical conclusions; there is too great a variation for that. The only conclusions that are well grounded are those of a qualitative estimation of the usefulness of the metals for cathode use in electroanalysis.

It seems that the use of silver is out of the question, for its losses in all kinds of solutions negate the advantage of a low initial cost. Gold appears suitable from the standpoint of corrosion alone, but because of its lack of rigidity, is easily spoiled mechanically, particularly by the beginner. Palau ware is apparently alright from the corrosion standpoint, and the tarnish it sometimes has is unweighable, but it has the handicap of being unobtainable in the gauze form, and in sheet form takes a deposit that is often nonadherent. Platinum fulfills all the requirements of the electroanalyst.

The author of this thesis believes that the best electrode is the one in which the surface exposed to deposition from the electrolyte is of the same metal as that deposited, plated or solid; this is of course general, as it is recognized that zinc may well be plated upon copper, etc.

A rigid gold gauze electrode would be the cheapest of the effective electrode materials tested.





PART VII  
BIBLIOGRAPHY

Volume II of Treadwell-Hall, Quantitative Analysis, has been made use of in the analytical work of this thesis, and references will be given to the pages noted, by the reference numbers in the text.

Classen-Hall, and Smith, recognized texts on the electrochemistry of electroanalysis, are also used and reference given to their works.

There is no current literature available in journals or transactions bearing on this subject.

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